

Internet Data Centres (IDC): design considerations for mission critical power system performance

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Abstract -Customers that operate or depend on IDC service provision often require mission critical availability. Various aspects of Uninterrupted Power System design and implementation must be carefully considered to ensure that this requirement is met. Faithful interpretation of design standards, high quality production control, intelligent operation and maintenance are among the important factors. The use of an emergency power system (UPS and gen sets) designed with the latest technology is key. Experience shows that the intrinsic reliability of the distribution segment (wiring, protection devices, interconnection, transfer units etc.) is also critical to the continuous availability of the power system. A significant portion of system failures is caused by problems in the distribution rather than by the failure of the power sources themselves. This paper describes how distribution reliability affects the reliability of the whole power supply system inside customer premises and it doesn't address the public utility networks. Utilization of advanced design of static switching architectures and special attention to the distribution segment dramatically improve the reliability of the total power system to accomplish mission critical objectives. Guidelines are proposed and their application is shown through real life case studies.

I. INTRODUCTION

Even before recent events around the world highlighted the vulnerability of telecom to electrical utility brownouts and blackouts, IDC Service Providers have been aware of the importance of a properly designed and implemented UPS. A steady trend of power plant disaggregation and distribution around the central office line up, that favoured the introduction of fairly dense, lower capacity power plants, is currently disrupted by massive power requirements concentrated in IDC's, heralding a new age for power plants in the fractional megawatt range.

A casual review of the promotional message popular among "web hotel managers" reveals that protection against electrical power disruption, security, and environmental ambient controls are highest on the list of benefits IDC managers offer to their customers. The reliable operation of the total energy system depends on automated vigilance and on preventive maintenance based on intimate understanding of the operating and failure modes of the system and its components. The discussion that follows draws heavily on our experience in equipping several major IDC's for European Customers, and on over 6 years of logged monitoring in more than 3000 installations around the world. Internet Data Centres are composed of large numbers of computer systems connecting millions of users to the Web. The guidelines

that are proposed at the end are the result of this body of experience. The required availability of the power supply system is of paramount importance. As a result the value of the presented solutions is high. The availability percentage is the key to evaluate the technical progress. In the past this value was 99.9 (three-nines), today it is, on average, 99.99 (four-nines) and the goal for the next future is to achieve a 99.9999 (six-nines) consistent percentage value.

II. EMERGENCY POWER SYSTEM

The latest technology offers the ideal solution to the perennial request for great availability and reliability of the power supply. The UPS (Uninterruptible Power Supply) is the device that can guarantee the required continuity and quality of supply, not only by protecting from mains failures but also from variations beyond tolerance. A double conversion UPS configuration guarantees, stable voltage and frequency. Double AC/DC conversion provides more guarantees than any other UPS architectures: the AC mains at the input is converted to DC by a total controlled rectifier; an inverter at the output rebuilds the sine wave. This stage can also provide frequency conversion. In normal operation mode the double conversion UPS always powers the load always through the inverter, thus completely decoupling the load from the electrical distribution, and protecting it from any disturbance that could cause a system malfunction.

A. Reliability of UPS architecture

Let us examine several UPS configurations, ranging from simple ones to complex parallel systems. This will provide a view of the options offered by various UPS systems and will allow the users to reach a higher level of reliability through the use of redundant elements.

The basic double conversion UPS has *no static switch*. The energy can flow through rectifier and inverter only. The next step relates to UPS with *static switch*. This one can use a stand-by additional supply in case of rectifier/inverter failure or in case of overload. Using these simple types of UPS it is possible to assemble any kind of parallel systems.

The two most important parallel architectures are: distributed parallel architecture and centralised parallel architecture.

The distributed parallel system consists of identical units with an on-board static switch assembly. It can also be fitted with a manual system bypass switch which can be

used for maintenance. This switch is indispensable for distributed systems with more than 2 units. In this case, if this switch is not included the system cannot be bypassed without cutting the power supply to the load. This configuration combines reliability and flexibility. The power capacity can be increased simply by adding another unit to the ones already in service. The centralised parallel system consists of units without on-board static switch assemblies. The units are all identical and the static switch is usually housed in a special cabinet. This static switch assembly can power the entire nominal load using the system stand-by input. The main advantage of the centralised parallel system is that it is less complex than the distributed system, in power and control subsystems. For this reason the MTBF of the centralised configuration is slightly higher than the MTBF of the distributed one. Higher MTBF results in a less flexible system, so is not advisable for installations in which the nominal load is subject to significant variations during the lifecycle of the UPS system. Table I shows the intrinsic MTBF of stand alone UPS and of parallel systems. These values were obtained by monitoring in field the illustrated UPS systems, produced by Chloride, within a period of 1 year (assuming Long Life Batteries and 2h MTTR).

TABLE I.
MTBF COMPARISON BETWEEN DIFFERENT UPS SYSTEMS.

UPS system	MTBF (kh)
UPS with no static by-pass	90
UPS with static by-pass	300
Distributed Parallel (2 units)	380
Centralised Parallel (2 units)	400

This remote control system (called LIFE 2000) can display the distribution of mains failures and disturbances as a function of their duration.

Our research, which is completely explained in [2], aimed to measure the different failure rates and recovery rates of interruptions due to the high voltage public distribution network and due to the low voltage distribution network inside customer premises, using the described system as a data collection tool. In [2] it is shown that the down time due to very long interruptions is not imputed to a poor quality of the public distribution network, but is related to the reliability of the low-voltage distribution segment upstream the UPS.

If we assume a constant failure rate for the public supply network and the distribution segment, and if we consider the Mean Down Time as a constant repair rate we obtain the following estimation of the failure rates, were MUT is the mean up time, whose reciprocal is the failure rate:

$$MUT_{PSN} \approx 500h \Rightarrow \lambda_{PSN} = 2 \cdot 10^{-3} h^{-1}$$

with $MDT_{PSN} \approx 100s$

For public distribution networks

$$MUT_{DISTR} \approx 9000h \Rightarrow \lambda_{DISTR} = 1,111 \cdot 10^{-4} h^{-1}$$

with $MDT_{DISTR} \approx 4650s (\approx 1,3 h)$

For an average low voltage distribution in customer premises

In the following the MTBF of the upstream distribution will be used as worst case reliability for the downstream distribution from the UPS.

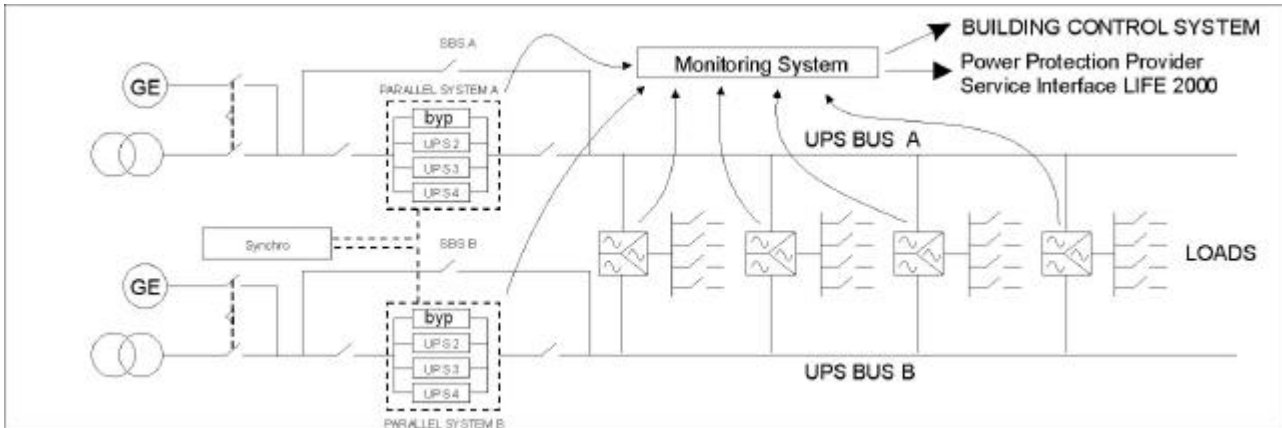


Fig. 1: Dual bus distribution with CROSS system static switch

III. RELIABILITY OF THE DISTRIBUTION SYSTEM

Our experience shows that the reliability of the distribution segment between the UPS and the loads affects the availability of the whole power protection system. Chloride's remote controlling system was used to measure power quality at the input of installed UPS.

IV. GUIDELINES FOR ACHIEVING MISSION CRITICAL AVAILABILITY

A. System level static switches (CROSS)

The static switch assembly, hereinafter referenced as CROSS, ensures a redundant power supply as near as possible to critical loads by enabling a controlled

switching between two independent AC power supply sources. Auto-switching is performed whenever the line that supplies power to the load is no longer within the acceptable tolerance values (voltage and frequency). Manual switching are always supervised by the control logic, allowing only secure manual transfers.

An important function of this device is the “Break Before Make” transfer. This ensures that the two lines are never connected in parallel. CROSS also ensures that switching

The two sources consist of redundant parallel UPS system powered by independent sources with the possibility of inserting electricity generating units in the event of prolonged mains power failure.

CROSS devices supply power to the load selecting the correct source.

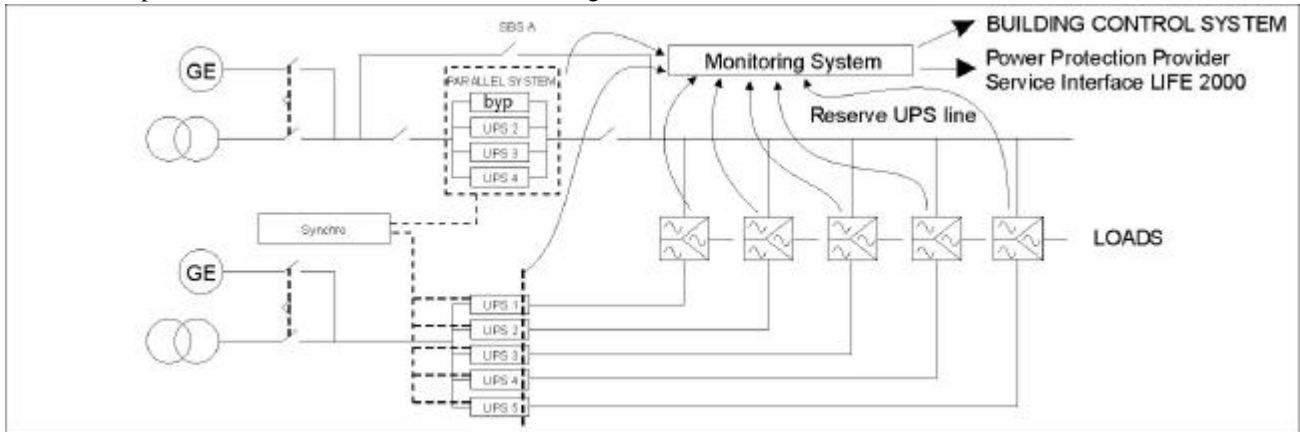


Fig. 2: Redundant distribution with reserve parallel system and CROSS controlled operations

between the two power supplies occurs under both synchronous and asynchronous conditions (relative to the voltage phase).

A considerable percentage of faults [2] in load supply (power supply failure) is caused by distribution faults. The use of System Static Switch assemblies enables the redundancy provided by two independent sources to be located as close as possible to the load. Therefore the amount of critical distribution (downstream from the CROSS) is greatly reduced compared to standard protection.

B. Guidelines for mission critical power protection systems

In order to obtain the level of continuity and system protection required for mission critical loads it is useful to take in considerations the following items, layout of the power system, technology and type of UPS and correct sizing of sources.

Achieving premium maintainability using the proper monitoring options. Monitoring options, allow the users to keep under observation the entire system involved in the distribution of power. It is easier to manage a power system if the power protection devices are communicating with each other and with a central monitoring system station.

The reliability of a system depending on parallel architectures can be increased using the Static Switches (CROSS). Some design guidelines are illustrated below. Figure 1 illustrates an example of static switch assembly use in a mission critical system.

The two UPS systems can be kept synchronous (output voltage phase coupling) to ensure that switching occurs as rapidly as possible. One more advantage of this configuration is the way CROSS behaves if there is an output short circuit. Under this circumstance CROSS disables switching, that is to say the short circuit is only powered by the live source when the short circuit occurs.

If the short circuit magnitude causes a significant fluctuation in the relevant source voltage, all the other CROSS assemblies are free to switch to the other source.

This means that distribution downstream of the CROSS assemblies is not in any way affected by the potentially damaging effects of short circuits on other branches. If the loads powered are dual feed, each supply line can be powered directly from the two UPS parallel systems, i.e. CROSS are strictly needed only for single feed loads. Since usually each UPS parallel system is rated to supply this entire load without redundancy, we will call hereinafter this architecture “N+N” (needed plus needed) [2].

The solution in figure 2 shows another configuration of single UPS systems and CROSS to ensure redundancy for critical loads. The UPS system A is a parallel system used as a very reliable standby source. Therefore it is only used in the event of a fault occurring to one or more of the single UPS (UPS 1, UPS 2, etc.) or due to the related downstream distribution. The nominal power of the standby system is such that simultaneous faults to more than one individual UPS can be accounted for. Synchronisation between the outputs of the UPS systems and the standby system has the same function as that seen in the previous solution i.e. to enable CROSS to switch

safely and as quickly as possible between sources. It is important to note how uninterruptible redundancy is created between the various synchronous sources without using parallel nodes (except the standby system). We will call hereinafter this architecture “N+1” (N UPS needed plus one stand-by system).

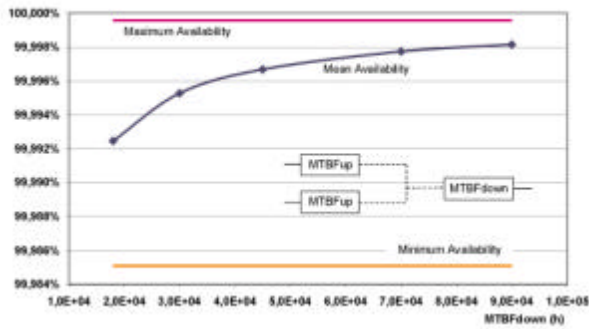


Fig. 3: Availability with CROSS

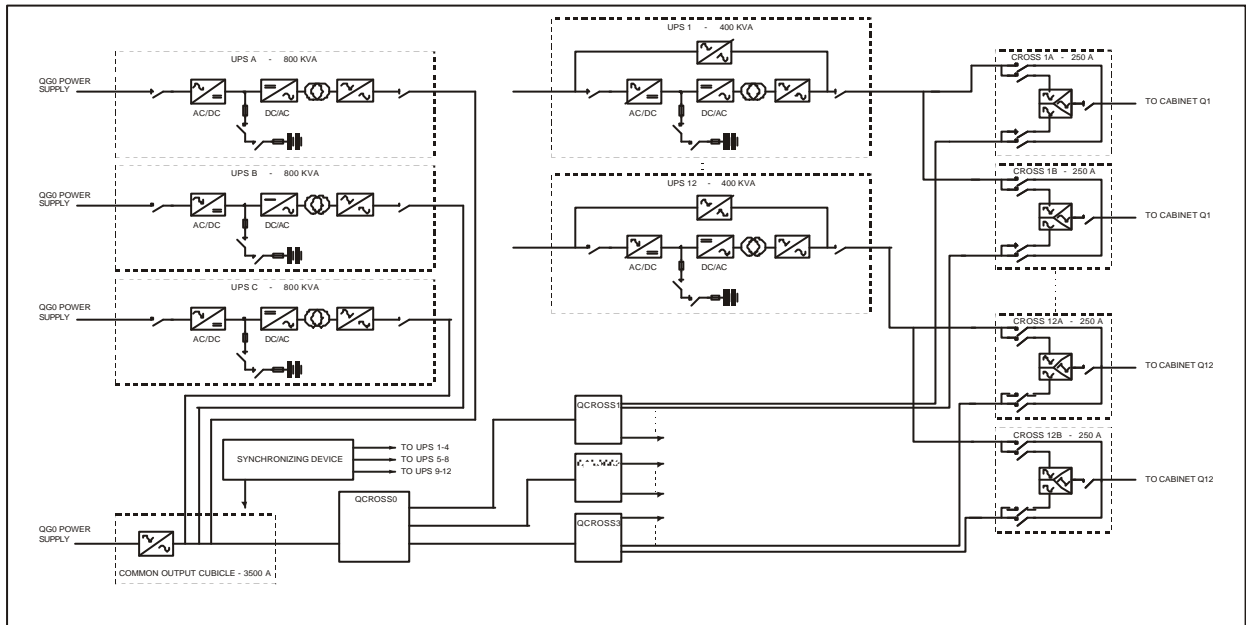


Fig. 4: CROSS controlled IDC emergency supply system

C. *UPS and parallel system cross reliability comparison*

The object of this paragraph is to focus on the reliability value of systems “N+N” (see fig. 1) using CROSS. By using CROSS, the distribution section downstream from the two UPS systems to the supplied load (supply path) is divided into two parts: upstream and downstream of the CROSS.

The MTBF value of the two upstream and single downstream single sections were varied to calculate the availability trend (complete details in [2]).

Figure 3 shows the availability achieved using CROSS system static switches. The graph shows the trend of the availability as the CROSS is moved toward the load (i.e. reducing the amount of distribution downstream from the CROSS) resulting in an increase in the MTBF of the distribution downstream CROSS against a decrease upstream the CROSS. The upper limit is the maximum availability obtainable if the distribution downstream of the CROSS has zero failure rate. The lower limit is the minimum availability obtainable with the same UPS system and the same distribution but no CROSS.

V. CASE STUDY

The system is made of 12 stand-alone UPS subsystems and a group of three paralleled UPS which are in stand-by state. In case of malfunction of any of the 12 stand-alone UPS, the standby system starts supplying the appropriate loads through CROSS proper switching action. In this

installation 24 CROSS are on constant watch to ensure the power quality required by mission critical loads. The parallel stand-by system is rated to supply the critical loads in presence of complete shut-down of up to six stand alone UPS subsystems. The case study, illustrated in fig. 4, refers to an IDC located in Italy with a nominal power capacity of 4800 kVA.

A. *Comparison of “N +N” and “N + 1” architectures*

We have considered the various systems previously described as repairable ones. For this comparison, we will

consider the two systems (N+N and N+1) as non repairable.

As it can be seen from the previous paragraphs, the two architectures proposed for IDC power systems that we want to compare are designed as follows:

1. A “N+N” system (needed + needed) with two centralised parallel UPS systems, each of them being capable of powering the entire installed load only if all the UPS are available; the load is made of dual feed loads banks (each device has two fully redundant supply line, A and B; if both lines are powered, the load is shared between supply line A and B). Each supply line, A and B, of each load bank is powered by two different cross static switches. Each cross switch is supplied by both the two different UPS parallel systems. The priority of the cross supply lines is arranged to share the load between the two UPS systems in normal operation. Each UPS system is made of 3 units of nominal apparent power A_N . Each UPS system is powered by a different primary source.
2. A “N+1” system (needed + 1) with N stand-alone UPS with bypass, each one of them powering one input (preferred source) of two cross static switches; the two cross static switches supplies the line A and line B of the same load bank as described above. The other input of all cross switches is supplied by a stand-by centralised parallel UPS system, made of 3 units of power A_N . The nominal power of the stand-alone UPS is $A_N/2$. The primary source powering the stand-by system is different from the primary sources powering the stand-alone UPS.

The power capacity of the first system is conditioned by the maximum power rating allowable for the static switch of each centralised UPS parallel system. For cost, reliability and components availability reasons, the maximum current rating for a single static switch in standard UPS architectures usually do not exceed 3500A, or 2400kVA system rating at 400V nominal three-phase voltage. Static switches with higher current rating can be manufactured as special products. As it is shown in the case study illustrated above, the nominal power rating required is 4800kVA. This means that using standard 800kVA UPS modules, architecture number one will require 2 complete “N+N” systems, each of them made of two centralised parallel systems with 3 UPS each (12 UPS in total). Architecture number two will require 12 stand-alone UPS with bypass of 400kVA nominal power (6 by 800kVA modules could have been used as well) and 3 by 800kVA modules in centralised parallel configuration for the stand-by system. For the two architectures, there are significant differences in the power plant costs, in the primary sources and in the UPS costs: the cost of architecture two is about 20% lower than architecture one. The reliability of a “N+N” architecture is higher than the “N+1”, but in order to satisfy load power requirements using only standard products, two “N+N” complete systems are needed to power the entire IDC.

There are differences in UPS power utilisation factors too (lower utilisation factor means lower conversion efficiency, thus more heat dissipation). In architecture “N+N” described above load is shared among the completely redundant UPS systems, so the utilisation factor of each unit (assuming that all UPS modules are normally functioning) is 50%. In architecture “N+1” the stand-alone units deliver 100% of nominal power, while the stand-by system runs normally at zero load in absence of failures in stand-alone UPS (the overall utilisation, for the case study, factor is 66.67%).

In order to esteem the reliability of the two architectures, it is supposed that the systems “N+N” and “N+1” are non-repairable systems, with constant failure rate for each component (no wear-out), and that the various sub-systems are independent and without memory.

Suppose also that the primary sources are always available; this was stated to simplify the calculations and to focus on the difference in reliability only of the UPS power systems and not of the primary sources. The only battery failures considered (for long-life VRLA batteries, see [4] for the definition of operative life) are those that causes tripping of DC protections. This hypothesis can be considered realistic if we have backup diesel generators for public network with automatic switch-gears and the battery autonomy is always enough to sustain the system during source changeovers.

The UPS failure rates are deduced from Chloride field experience and depend on utilisation factors. The corrective factors for the failure rates were deduced using MIL specifications [5] for the power semiconductors. In architecture “N+1” the base UPS failure rate is multiplied by 50 for the stand-alone UPS, while the failure rate for the UPS in the stand-by system is multiplied by 5. In architecture “N+N” the failure rate for UPS in both systems is multiplied by 25. Stress factor was not applied to static switches. The results of calculations (see Appendix) are illustrated below. System failure is defined as the interruption of power supply to a single dual feed load bank (or row). Double architecture “N+N” has a MTTF (considering the single load bank) of $139 \cdot 10^3$ hours (about 15.9 years) while the architecture “N+1” has a MTTF of about $146 \cdot 10^3$ hours (about 16.7 years). MTTF of “N+1” is 1.05 times the MTTF of double “N+N”; practically the reliabilities of both systems can be considered equal.

Considering the systems repairable, as it is in real world, if any sub-system is repaired as soon as the first fault occur (both systems are fault tolerant in any section), the MTBF of both will explode in the range of the thousands of years.

In real cases (repairable systems), the reliabilities of architectures “N+1” and “N+N” are very close, while “N+1” always offer sensible installation costs reduction and more efficient power utilisation of UPS. Maintainability is always a key factor: in order to obtain five-nines and six-nines availability systems must be fault

tolerant (even respect to human errors) and easily repairable with spares always available. Efficient maintenance is achieved if the diagnosis and monitoring system is able to signal any unrevealed failure in real time. Therefore a high-quality power protection solution provider must be able to deliver a responsive service when a corrective maintenance action has to be taken and the customer must take care of his system by subscribing effective preventive maintenance contracts, which include remote monitoring of the UPS and cross switches operated by the manufacturer.

VI. CONCLUSIONS

IDC centres often require mission critical availability. The faithful interpretation of design standards, an high quality production control, an intelligent operation and maintenance are among the important factors. The use of an emergency power system (UPS and gen sets) designed with the latest technology is key. Our field experience shows that the intrinsic reliability of the distribution is also critical to the continuous availability of the power system. A significant portion of system failures is caused by problems in the distribution rather than by the failure of the power sources themselves. The advanced design of static switching architectures, using CROSS and a special attention to the distribution segment can dramatically improve the reliability of the total power system to accomplish mission critical objectives.

“N+1” is the most cost-effective solution and it can be considered the preferred architecture for high-power mission critical systems. Architecture “N+N” can be considered the preferred architecture for low and medium power systems.

VII. ACKNOWLEDGEMENT

The authors would like to thank prof. Enrico Sangiorgi of DIEGM, University of Udine, for valuable discussion on system reliability.

VIII. APPENDIX

Estimation of reliability of systems “N+N” and “N+1” was carried out under the following general assumptions:

- systems are non repairable;
- the base failure rate is constant over time, sub-systems are independent and without memory. Thus exponential reliability is assumed for each sub-system;
- stress factors are applied to base failure rates for UPS depending on their average utilisation factor;
- primary sources are always available

Reliability $R(t)$ is the probability that a device can operate within specified limits during time interval $[0,t]$ in given conditions. MTTF (see glossary) is calculated as:

$$MTTF = \int_0^{\infty} R(t) dt$$

First the $R(t)$ was calculated defining the system available for each load bank if there is enough power deliverable to the users from the UPS or through the bypass static switches, and not considering the cross static switches reliability. For N+N systems we have:

$$R_{N+N}(t) = \left[\left(e^{-\lambda_{ssof} t} + R_{red}(t, \frac{N}{2}, N, R_{UPS}(t)) - e^{-\lambda_{ssof} t} \right) \cdot R_{red}(t, \frac{N}{2}, N, R_{UPS}(t)) \right] e^{-\lambda_{sssf} t}$$

where $R_{UPS}(t)$ is the reliability of a basic double conversion UPS (rectifier, battery, inverter without static bypass) and λ_{ss} (open failure and short failure) are the failure rates of a static switch and

$$R_{red}(t, k, h, R(t)) = \sum_{i=k}^h C_h^i R^i(t) (1 - R(t))^{h-i}$$

If multiple “N+N” systems are required to power the entire load, the reliability is $(R_{N+N}(t))^{N_{sist}}$.

The MTTF showed in the previous paragraph was calculated assuming $N = 3$ and $N_{sist} = 2$.

For N+1 system, it was supposed there are $N = 12$ stand-alone UPS with bypass and $M = 3$ UPS in the centralised parallel stand-by system; reliability is:

$$R_{N+1}(t) = 1 - \prod_{i=1}^4 (1 - P_i)$$

where

$$P_i = P_a \left(\frac{N}{2} + 2(i-1) \right) P_b (M - (i-1)) \text{ for } i = 1 \text{ to } 3$$

$$P_i = P_a (N) \text{ for } i = 4$$

$$P_a (l) = C_N^l R_{UPSBYP}^l(t) (1 - R_{UPSBYP}(t))^{N-l}$$

Finally, the reliability of cross static switches was included in the calculation, using a fair approximation: being the load banks line A and B supplied by two crosses, the power supply to one load bank is assured if at least one of the two cross switch is functioning correctly (this leads to an underestimation of reliability). Thus:

$$R^*(t) = (R_{N+N}(t) \text{ or } R_{N+1}(t)) \cdot R_{red}(t, 1, 2, R_{cross}(t))$$

where

$$R_{cross}(t) = (2e^{-\lambda_{ssof} t} - e^{-2\lambda_{ssof} t}) e^{-\lambda_{sssf} t}$$

$$P_b(l) = \left(e^{-\lambda_{ssof} t} + R_{red}(t, l, M, R_{UPS}(t)) - e^{-\lambda_{ssof} t} \right) \cdot R_{red}(t, l, M, R_{UPS}(t)) e^{-\lambda_{sssf} t}$$

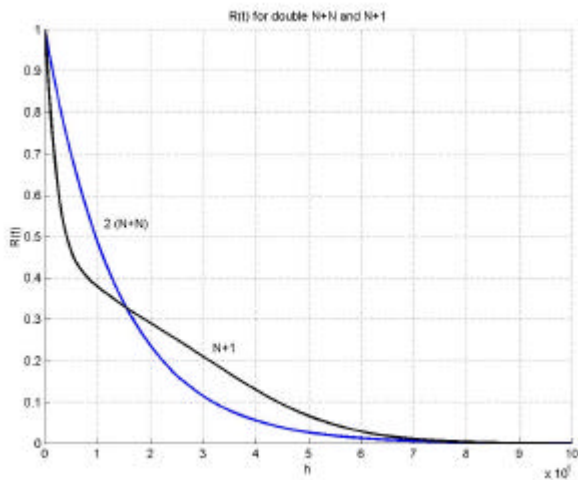


Fig. 5: Reliability curve

Reliability curves of power supply for a single load bank for double “N+N” and “N+1” are shown in figure 5

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X. GLOSSARY

MTBF (mean time between failures): expected value of operating time between failures
 MTTF (mean time to failure): expected value of operating time to failure
 MTTR (mean time to restoration): expected value of restoration time
 MUT (mean up time): expected value of up time
 MDT (mean down time): expected value of down time
 (Definitions from standard IEC 50 (191), ed. 1990)

XI. BIOGRAPHIES



Emiliano Cevenini was born in Bologna, Italy, on April the 16th, 1970. He graduated from University of Bologna in Electronic Engineering. He joined Chloride Power Protection Italy in 1997 as R&D project leader for the development of high-range UPS for USA market. From year 2000 he is in charge of the technical marketing division (Chloride Support and Consulting) and he is responsible of the technical sales support division. He is member of International Electrotechnical Commission, SC22H (uninterruptible power supplies) and he is currently involved in the development of a new IEC technical standard on system level static transfer switches.
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Christian Bertolini was born in Parma, Italy, on July the 19th 1973. He graduated from University of Parma in Electronic Engineering with a degree thesis about electromagnetic compatibility applied to UPS systems. He joined Chloride Power Protection in year 2000 as R&D UPS engineer. From year 2001 he is a technical consultant for UPS installation projects in Chloride Support and Consulting division. (Email: Christian.Bertolini@chloridepower.com)



Alberto Ariatta, born in Milan, Italy on January 5, 1961. He graduated as Electrotechnical Engineer from Politecnico in Milan in 1985, and in 1992 becomes, with the responsibility of Electrical Plants, Managing Director of Ariatta Ingegneria dei Sistemi (www.ariatta.com), inheriting its 30-year experience in Design and Site Supervision of M&E Plants. In the last years Ariatta Ingegneria dei Sistemi grew its experience in Telecommunication becoming a highly specialized M&E Designer for Internet Data Center and can list among its most important Customers almost all European Telecom Companies operating in Italy.
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